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Evidence that non-social autism traits in the general population are correlated with spatial processing of biological motion

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ABSTRACT

Biological motion perception theories of autism hold that differences in how biological motion is processed help explain the social difficulties experienced by individuals with autism. However, evidence for this theory is mixed, with some studies finding such differences, but others not. Recent meta-analytical work suggests that autism may be specifically associated with differences in the temporal processing of biological motion. In the current study, we correlated autism traits in the general population ($N = 193$) with performance on a biological motion perception task while manipulating both spatial and temporal stimulus properties by means of spatial and temporal scrambling. In contrast to our hypothesis, we found no correlation between the effect of temporal scrambling and autism traits (operationalized as AQ scores). We did, however, find a correlation between the subscale attention to detail and the effect of spatial scrambling. This suggests that autism-related differences in local-global processing are associated with the degree to which spatial information is used to bind local motion signals in a global movement percept. However, correlations were small and further research will be needed to confirm this finding.

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Individuals with autism spectrum disorder (henceforth: autism[1]) show both social and non-social differences in behaviour. At the social level, autism is characterized by persistent difficulties in social communication and interaction. At the non-social level, it is characterized by restricted and repetitive behaviour, interests, and activities (American Psychiatric Association, 2013). Although different theories have been developed to explain these differences, most focus either on the social (e.g., Baron-Cohen, 2000; Baron-Cohen et al., 1985; Senju, 2012) or on the non-social domain (e.g., Frith & Happé, 1994; Happé & Frith, 2006; Mottron et al., 2006). A theory that brings both domains together is the theory that autism is associated with differences in biological motion perception (Federici et al., 2020; Pavlova, 2012; Todorova et al., 2019; Van der Hallen et al., 2019). This theory argues that individuals with autism have a more local than global processing style (e.g., Frith & Happé, 1994; Happé & Frith, 2006; Mottron et al., 2006) and for that reason have difficulties with integrating local motion signals into a global percept of biological motion (Van der Hallen et al., 2019). This, in turn, may make it more difficult for individuals with autism to extract the relevant social signals from biological motion (Pavlova, 2012) and may partly explain their social difficulties (Federici et al., 2020; Todorova et al., 2019).

Supporting differences in biological motion perception, three recent meta-analyses found evidence for reduced processing of biological motion in autism (Federici et al., 2020; Todorova et al., 2019; Van der Hallen et al., 2019). However, these meta-analyses also revealed large variability, with some studies indicating that adults with autism are less able to detect biological motion than typically developed adults (e.g., Hsiung et al., 2019; Nackaerts et al., 2012), but other studies finding no such differences

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(e.g., Cusack et al., 2015; Edey et al., 2019). One possible reason for these differences is that individuals with autism have difficulties only with some aspects of biological motion processing and hence that there are moderators that determine whether differences in the perception of biological motion can be detected.

A moderator that appeared across two meta-analyses is the level of processing required. More specifically, both Todorova et al. (2019) and Federici et al. (2020) found that differences between individuals with and without autism become larger in tasks that require extracting socially relevant information from biological motion (e.g., someone's emotional state) than in tasks that only require detecting biological motion. This aligns with recent perspectives emphasizing the influence of top-down processes, such as attention, task context, and active information seeking, on biological motion perception (e.g., Knight et al., 2022; Ricou et al., 2025). These accounts highlight that perceptual differences in autism may be shaped in part by broader social-cognitive factors. Nonetheless, both meta-analyses also indicated that differences are detectable even in very simple tasks that did not require the extraction of socially relevant information, suggesting that lower-level perceptual mechanisms may also play a role.

In line with this, a second moderator identified by Federici et al. (2020) appears to be a more fundamental one. They found that differences may depend on exactly what aspect of biological motion processing is measured. A common task to study biological motion perception is to ask participants to detect the presence or walking direction of a point-light figure in an array of scrambled noise (Bertenthal & Pinto, 1994; Chang & Troje, 2009b, 2009a). In such tasks, biological motion perception is quantified as the difference in accuracy between a condition where the figure is shown unaltered and a condition where the figure is scrambled. Importantly, there are two types of scrambling. When spatial scrambling is used, the figure's dots are displaced randomly within a certain area, but the temporal contingency between them is maintained (e.g., in a walking movement, the left and right ankle dots will move in opposite directions). In contrast, when temporal scrambling is used, the dots are shown in their original location, but the phase of the dots is scrambled, thereby disrupting this temporal contingency.

Federici and colleagues (2020) found that differences in biological motion perception between individuals with and without autism were restricted to the subset of studies using temporal scrambling. According to the authors, this suggests that it is especially the temporal properties of biological motion that are processed differently in autism. Although this is consistent with other work arguing that reduced global processing in autism can be traced back to problems with temporal binding (Brock et al., 2002; Wallace & Stevenson, 2014), a limitation is that the included studies may have also differed on other properties than the tested moderator. With the current study, we aimed to systematically test whether autism traits are associated with altered temporal processing of biological motion. Using a dimensional approach, we manipulated both temporal and spatial scrambling and correlated the effects with autism traits measured in a large community sample (Baron-Cohen et al., 2001)

Methods

Ethics and open science statement

The study was preregistered (https://aspredicted.org/8MJ_LN7) and approved by the local ethics committee of the Faculty of Psychology and Educational Sciences at Ghent university (2023-019A). The data and analysis scripts are available on the Open Science Framework: https://osf.io/rg74p/.

Participants

In line with our preregistration, we collected a sample of 193 participants ($M_{age} = 29.56$, $SD_{age} = 6.79$, $range_{age} = 19\text{-}45$, 69 female, 119 male, 2 non-binary, 3 chose not to specify their gender). This sample size was based on a power analysis aiming for 80% power to detect a small-to-medium correlation of $r = 0.20$ at $\alpha = .05$. All participants were recruited on Prolific (https://www.prolific.co/) using the following criteria: aged between 18 and 45 years old, fluent in English, having at least a secondary education degree, having normal or corrected-to-normal vision, and having an approval rate of $\geq$70%. Participants in our sample were not screened on having an autism diagnosis. Our choice to focus on interindividual differences rather than comparing a group

with and without autism was motivated by two arguments. First, previous research has found correlations between autism traits in a neurotypical sample and biological motion perception (Van Boxtel et al., 2017). Second, a dimensional perspective has been supported by evidence that autism traits are normally distributed in the population and that individuals with an autism diagnosis represent the tail of this distribution (Abu-Akel et al., 2019; Bralten et al., 2018; Constantino & Todd, 2003; English et al., 2021; Lundström et al., 2012). On this view, a large deal of variance is lost by only considering the tail.

Task and procedure

Participants were recruited via Prolific. They were instructed to complete the study on a desktop or laptop computer in a quiet environment. Participants were then directed from Prolific to the informed consent form, asked to read it, and to indicate whether they consented to all statements in the form. If yes, they were directed to an interface that contained some general information about the study and a button to start the experiment. After clicking this button, the instructions of the biological motion task appeared. These instructions told participants that they would see point-light figures walking to the left or right. The instructions further said that these figures would appear either normal or distorted and that participants' task was to indicate the figures' walking direction by clicking a left or right button. This explanation was accompanied by three GIFs showing a normal walker, a spatially scrambled walker, and a temporally scrambled walker. Next, participants were told that the walkers would be embedded in noise, and three more examples were shown with noise added. Finally, participants were directed to the experimental platform where they could complete the task (https://www.biomotionlab.ca/Experiments/signin).

The experimental task and stimuli were created and administered using the Biological Motion Lab system (https://www.biomotionlab.ca/Experiments/documentation/index.html; a demonstration version of the task can be accessed at https://www.biomotionlab.ca/Experiments/BMLkit/bmlstimuli?expid=76&isTesting=1). The experimental task consisted of 96 trials, each showing a point-light walker randomly drawn from the 8 cells of our walking direction (left vs. right) x spatial scrambling (scrambled vs. unscrambled) x temporal scrambling (scrambled vs. unscrambled) design. For the scrambling, we used the built-in parameters of the Biological Motion Lab systems (scrambling degree = 100%). Spatial scrambling was implemented by randomly displacing each dot's trajectory within the restricted display area (Troje & Westhoff, 2006). In this manipulation, the walker remains centred on the screen and local motion trajectories are preserved, but the coherent global shape of the figure is disrupted through the reassignment of individual dot trajectories. Temporal scrambling was implemented by independently randomizing the phase of each dot's motion trajectory within the walker's gait cycle, such that all dots started their motion at different, randomly assigned time points (Troje & Westhoff, 2006). Walkers were embedded in a mask of 100 randomly positioned dots, each with a limited lifetime of 170 ms, after which it was replaced by another dot in a different location (see Troje & Westhoff, 2006, for a similar task and procedure). Together with the stimulus, two response buttons were shown, allowing participants to indicate whether the walker moved left or right. Note that we chose to use a discrimination task instead of the also frequently used human detection task, as it is slightly more challenging and thus better suited for our adult sample. The stimuli were shown for 1.5 s, after which they disappeared. However, the response buttons remained visible until participants responded, followed by an inter-trial interval of 0.5s. When no response was provided within a 4 s window, the trial was not saved and a replacement trial was added at the end of the task. In total, the task lasted 5-10 min.

After the experiment, participants were directed to a survey where they were asked to complete the Autism Spectrum Quotient (AQ; Baron-Cohen et al., 2001). The AQ is a 50-item questionnaire that can be used to measure autistic traits in the general population. All items are scored on a four-point scale going from "definitely agree" (1) to "definitely disagree" (4) and can be subdivided into five subscales (social skills, communication, attention switching, attention to detail, and imagination), each with a reasonable to good internal consistency ($.63 \leq \alpha \leq .77$). Cronbach's alpha of the total scale was .87 in the current study. Cronbach's alpha of the subscales was .84 for social skills, .78 for communication, .70 for attention

switching, .76 for attention to detail, and .57 for imagination. Total AQ scores ranged from 81 to 164, with 16 participants scoring above the clinical cut-off identified by Baron-Cohen et al. (2001).

Preregistered analyses and results

We first performed a 2 (spatial scrambling) x 2 (temporal scrambling) repeated measures ANOVA on participants' error rates in the task (Figure 1). This revealed a significant main effect of both spatial scrambling, $F(1, 192) = 1140.42$, $p < .001$, $\eta_p^2 = 0.85$, and temporal scrambling, $F(1, 192) = 107.56$, $p < .001$, $\eta_p^2 = 0.65$. The main effect of spatial scrambling indicated that error rates were higher in the spatially scrambled (39%) than non-scrambled (9%) condition. The main effect of temporal scrambling indicated that error rates were higher in the temporally scrambled (28%) than in the temporally non-scrambled (21%) condition. The interaction between spatial and temporal scrambling was not significant, $F(1, 192) = 3.61$, $p = .059$, $\eta_p^2 = 0.02$.

Second, we calculated the correlation between the spatial and temporal scrambling main effects and the total AQ score. This revealed that neither the effect of spatial scrambling, $r = -0.12$, $p = .111$, nor the effect of temporal scrambling, $r = -0.01$, $p = .854$, correlated with the AQ total score. Third, we calculated correlations between the two main effects and each of the five subscales, corrected for testing multiple scales using FDR-correction. This revealed that the spatial scrambling effect was correlated with the attention to details, $r = -0.18$, $p = .027$, and the imagination subscales, $r = -0.19$, $p = .027$, but not with the social skills, $r = -0.03$, $p = .837$, communication, $r = -0.02$, $p = .837$, and attention switching subscales, $r = 0.02$, $p = .837$. The temporal scrambling effect, on the other hand, was correlated with none of the five subscales: attention to details, $r = 0.05$, $p = .880$, imagination, $r = -0.09$, $p = .880$, social skills, $r = 0.02$, $p = .966$, communication, $r = 0.00$, $p = .966$, and attention switching, $r = -0.05$, $p = .880$.

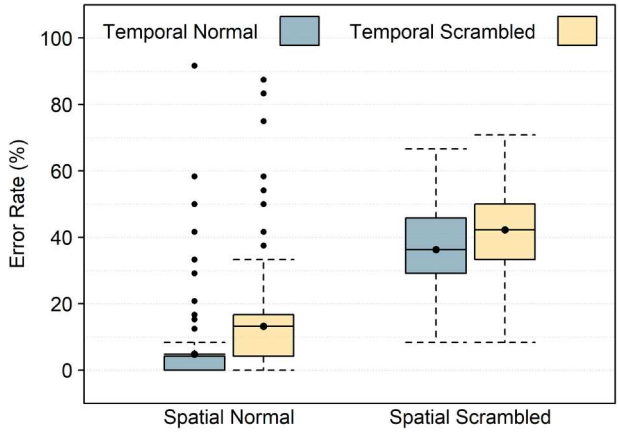

Figure 1. *Effect of spatial and temporal scrambling on biological motion perception accuracy* Note. Boxplots show the mean instead of the median to match the statistical analysis.

Fourth, for the two scales that correlated significantly with spatial scrambling, we tested whether the correlation with spatial scrambling was significantly higher than the correlation with temporal scrambling (Figure 2). A Pearson *Z*-test for dependent measures showed that this was the case for the attention to details scale, $z = 2.14$, $p = .032$, but not for the imagination scale, $z = 0.88$, $p = .380$. Finally, in a last preregistered analysis, we tested whether the stronger correlation between attention to details and the spatial scrambling effect than between attention to details and the temporal scrambling effect persisted after excluding 3 participants with an overall error rate > 50%. Although the correlation with the spatial scrambling effect, $r = -0.15$, $p = .036$, remained numerically stronger than the correlation with the temporal scrambling effect, $r = 0.05$, $p = .471$, after excluding these participants, the Pearson *Z*-test comparing both correlations was no longer statistically significant, $z = 1.89$, $p = .059$.

Exploratory analyses and results

A limitation of the preregistered analysis is that using error rates in a parametric analysis violates the normality assumption, as error rates are usually skewed and bound by 0 and 1. A better approach is, therefore, to use logistic models that explicitly model the binomial distributions underlying the dependent variable (i.e., error or correct; Jaeger, 2008). To this end, as an unregistered secondary analysis, we also fitted a generalized linear mixed effects model with a binomial link function and both spatial and temporal scrambling as factors, together with the normalized scale scores of the respective scale as a continuous predictor, and a maximal random slopes structure. As before, FDR was used to correct for testing multiple scales. This revealed that none of the scales modulated the effect of temporal scrambling on task accuracy, all $p \geq .163$, whereas attention to details

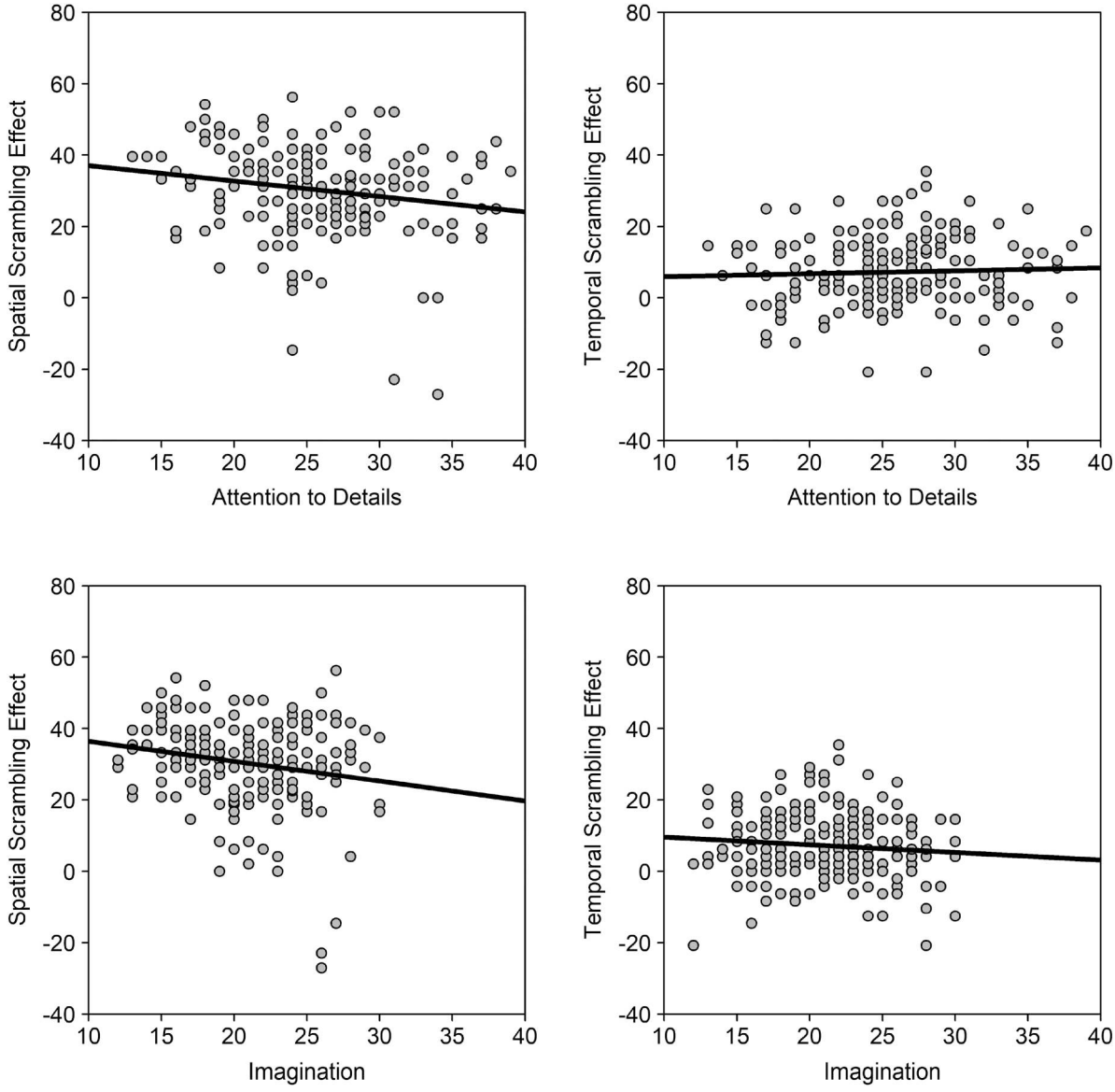

Figure 2. *Correlations between the effect of scrambling and autism traits* Note. Scatterplots showing the correlation of the spatial and temporal scrambling effects with the AQ subscales attention to details and imagination, together with linear regression fit lines.

modulated the effect of spatial scrambling on task accuracy, $z = 2.89$, $p = .019$, but the other scales did not, all $p \geq .368$.

Discussion

Previous research has found mixed evidence for the hypothesis that autism is associated with differences in biological motion perception. A possible reason for this is that only certain aspects of biological motion are processed differently in autism. In particular, a recent meta-analysis suggested that autism may be associated specifically with differences in processing the temporal properties of biological motion (Federici et al., 2020). In the current preregistered study, we aimed to test whether autism is specifically associated with altered temporal processing of biological motion. We correlated autism traits in the general population with performance on a biological motion perception task in which both spatial (spatial scrambling) and temporal (temporal scrambling) motion properties were manipulated. In contrast to our hypothesis, we found no significant correlation between the effect of temporal scrambling and overall autism traits, as assessed by the total score on the AQ (Baron-Cohen et al., 2001). Instead, we found evidence for a correlation between the effect of

spatial scrambling and a specific subscale of the AQ, namely the "attention to details" scale.

These results differ from the findings of the meta-analysis of Federici and colleagues (2020), who found that only temporal scrambling influenced biological motion perception in individuals with autism. There are three possible reasons that might explain this difference. First, a limitation of meta-analyses is that the studies included in a comparison may differ not only on the dimension of interest but also on other dimensions. In other words, it is possible that the effect of temporal scrambling found by Federici et al. (2020) was explained by confounding factors. Second, whereas Federici et al. (2020) focused on studies comparing a group of individuals with an autism diagnosis with a group of individuals without such a diagnosis, the current study took a dimensional approach, looking at variations in autism traits in the general population. While the dimensional approach has proven useful for studying biological motion perception (e.g., Van Boxtel et al., 2017), there is an ongoing debate about the extent to which studies measuring autism traits in the population generalize to individuals with an autism diagnosis (Frazier et al., 2023; Sasson & Bottema-Beutel, 2022). For example, there is a chance that adults with elevated autism traits, but no formal diagnosis, have other compensatory strategies than adults with an autism diagnosis. Hence, an important task for future studies will be to extend the current research to samples with an official diagnosis. Third, the three studies that drive the temporal scrambling effect in the meta-analysis by Federici et al. (2020) were conducted with young children. Therefore, it could be that the effect of temporal scrambling on biological motion perception is influenced by age. Meta-analyses on biological motion in autism reported conflicting results, with the meta-analysis by Todorova et al. (2019) identifying age as a moderator, while the meta-analyses by Federici et al. (2020), and Van der Hallen et al. (2019) found no such effect. Given that the role of age remains unclear, future research should address whether age plays a role in the spatial and temporal processing of biological motion in autism.

Interestingly, while we did not find correlations between overall autistic traits and the effect of temporal scrambling, we did find correlations with the effect of spatial scrambling, but only for a specific subset of autism traits, namely attention to detail. The negative direction of the correlation suggests that more autism traits are associated with a smaller increase in errors caused by spatial scrambling. Since an effect of spatial scrambling requires sensitivity to the spatial aspects of biological motion to begin with, this suggests that individuals with more autism traits rely less on spatial information when processing biological motion. In other words, spatial scrambling primarily disrupts performance in individuals with less autism traits. The correlation with the attention to detail subscale is not surprising, given that biological motion perception relies on the integration of local motion signals into a global movement percept (Giese & Poggio, 2003). As a result, individuals who have a tendency to focus on details may be less inclined to bind point-light dots into a point-light figure and therefore perform worse when having to identify the walking direction of this figure, which would be in harmony with a more local than global processing style, which is well-documented in autism (e.g., Frith & Happé, 1994; Happé & Frith, 2006; Mottron et al., 2006).

Our finding that non-social autism traits are correlated with spatial processing of biological motion is in line with findings of a recent eye-tracking study relating preferences for biological motion to social skills in a large sample of children with and without autism (Mason et al., 2021). The results revealed a weaker preference for biological motion in the group with vs. without autism, but no relation between biological motion preference and social skills was found. Although our results support this work, it should be noted that we found only small correlations and that the statistical evidence was relatively weak. Therefore, even though our study was preregistered, replication will be needed before strong conclusions can be drawn.

In conclusion, we found no evidence for the hypothesis that autism, at least when measured dimensionally, is associated with differences in processing the temporal properties of biological motion (Federici et al., 2020). In contrast, we found evidence that one specific cluster of traits – attention to detail – is correlated with spatial processing of biological motion. However, as the evidence was relatively weak, further research will be needed to fully understand the relationship between autistic traits and biological motion perception, and to understand

whether this relationship generalizes to individuals with an autism diagnosis.

Note

1. We use an abbreviated version of the diagnostic term, and refer to an individual with a diagnosis of autism spectrum disorder, as an individual with autism. With this, we do not intend to take a stance in the ongoing person-first versus identity-first debate, in which there is currently no consensus (De Laet et al., 2025). We acknowledge and respect different language preferences to refer to a person with a diagnosis of autism spectrum disorder.

Disclosure statement

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